ANALYSIS OF ELECTRICAL PROPERTIES OF $In_{0.12}Al_{0.88}N$/GaN HEMT TRANSISTOR SUPPORTED BY TCAD MODELING AND SIMULATION

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1. Introduction

The GaN-based heterostructure is a promising candidate as a field-effect transistor (HFET) due to its wide band gap, superior carrier saturation velocity, thermal conductivity, and high breakdown field which are required for high temperature, high power, and high speed applications [1,2]. One of the big problems arising at high bias operation is the significant increase of drain current. This can be caused by the carrier avalanche multiplication in the channel, increased parasitic conductivity in the buffer layer, particularly due to the activation of the defect states, and increase of a gate current as well. Those issues limit the breakdown voltage as well as the smallest source-to-drain distance design particularly for high power applications [3]. The paper deals with analysis of electrical *I-V* characteristics of power HEMT structures. All dimensions and parameters of the simulated structure were calibrated to get a good agreement with the corresponding real structure. We considered physical effects as surface charges and deep level traps in our simulations. In this paper we present results obtained from electrical measurements on the real structures and their physical interpretation supported by 2-D modeling and simulation.

2. Device structure and numerical simulation

The investigated InAlN/GaN heterostructures consist of an AlN buffer layer 300 nm thick on SiC substrate, followed by a 2.5 µm GaN layer with a 1 nm AlN spacer layer and 7 nm $In_{0.12}Al_{0.88}N$ barrier layer on a top [4]. Schematic view of our structure is shown in Fig.1 where we can see individual layers and detail of the structure on the top. The drain and source contacts were prepared by evaporation of Ti/Al/Ni/Au metal stack and subsequent rapid thermal annealing. The gate contact was formed using Ni/Au metallization [4].

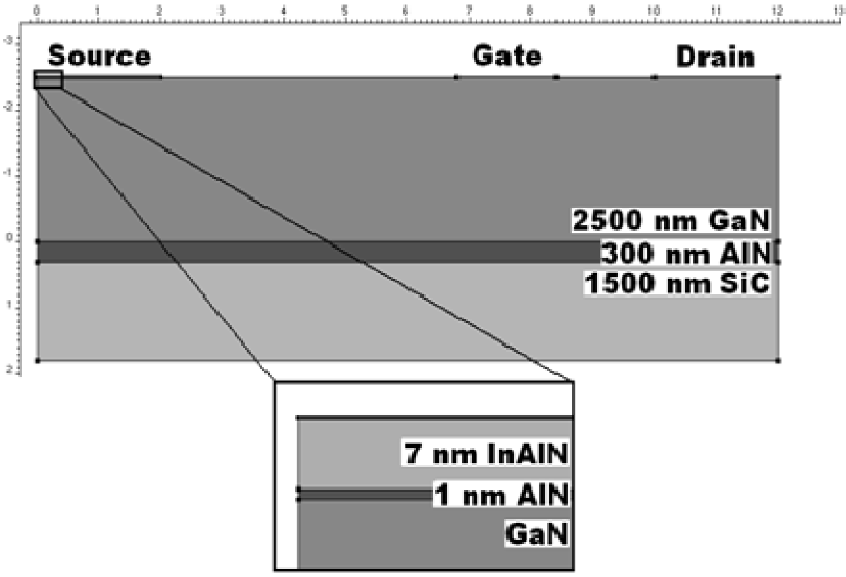


Fig.1: *Schematic view of InAlN/GaN HEMT structure.*

In our simulations we consider gate contact with Schottky barrier height 1.7 eV. Gate to drain distance is 1.6 μm, gate to source distance is 4.8 μm and gate length is 1.6 μm. The drain and source contacts were simulated as ohmic contacts. Electro – physical behavior of our heterostructure was simulated in DESSIS tool using drift - diffusion model [5]. The rapid increase of a drain current I_D with a small change of V_{DS} (beginning of breakdown) can be attributed to avalanche multiplication. Avalanche multiplication for a used drift-diffusion model is driven by the component of the electric field that is parallel to the current flow. Electron–hole pair generation due to impact ionization requires certain threshold field strength and the possibility of electron acceleration to get a minimum energy for generation of electron-hole pair. If the width of a space charge region is greater than the mean free path between two ionizing impacts, charge multiplication occurs, which can cause electrical breakdown. The reciprocal of the mean free path is called the ionization coefficient α. With these coefficients for electrons and holes, the generation rate can be expressed as:

$$G^{II} = \alpha_n n v_n + \alpha_p p v_p \tag{1}$$

where $v_{n,p}$ denotes the drift velocity [5].

3. Experimental results and discussion

In the presented article we analyze the electrical *I-V* characteristics of the HEMT transistor. To calibrate the parameters of electro physical models used for simulation we tried to obtain very good agreement between experimental and simulated transfer characteristics.

In Fig. 2 the measured transfer characteristics for V_{DS} = 0 V to 8 V are shown. We select the one for V_{DS}=8V to calibrate our model. We refer to very good correlation of simulated and measured transfer characteristics presented in Fig.3., where we can see that simulation match measurement very well and we can extract the value of threshold voltage of used transistor which is V_{th} = -3V, approximately.

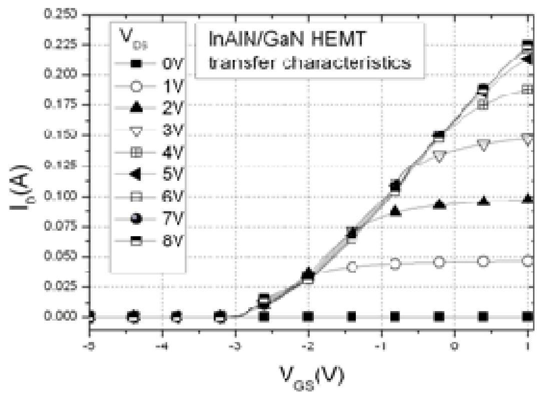


Fig. 2: *Measured transfer characteristics for V_{DS}=0V to 8V*

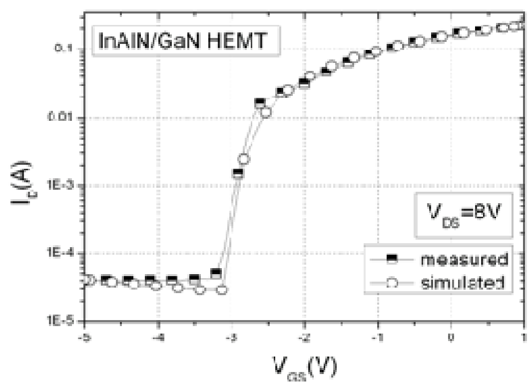
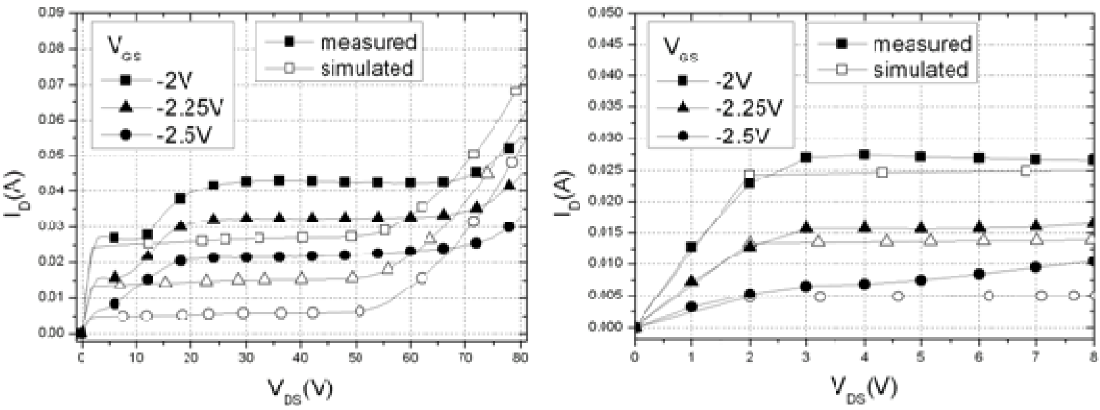


Fig. 3: *Comparison of simulated and measured transfer characteristics for V_{DS}=8V*

Further we measured the output characteristics of HEMT up to 80 V where the current starts tend to breakdown. We can clearly see some anomalous behavior of output characteristics for drain voltages above 15 – 20 V (Fig. 4.a). It looks like a second channel is opened which corresponds to current increase and is then again saturated. We observed such phenomena on almost all samples under investigation. We simulated the output characteristics where we varied the concentration of deep traps. The obtained results from electrical simulations compared to experimental curves for V_{GS} = -2 V, -2.25 V and -2.5 V are shown in Fig.4.



a) *b)*

Fig. 4: *Comparison of simulated and measured output characteristics a) up to V_{DS} = 80V b) detail up to V_{DS} = 8V*

We see in Fig. 4.b that for low voltages up to 10 V the agreement between experimental and simulated characteristics is very good, for higher drain voltages there are significant discrepancies between experimental and simulated curves. With the physical models we used we are not able to explain the further increase and second saturation of drain currents. For higher drain voltages in the transistor saturation region some other physical effects with calibrated model parameters should be taken into account to improve the significant discrepancy between simulated and experimental characteristics in the saturation region.

4. Conclusion

The results from electrical measurements and 2-D simulations of InAlN/GaN HEMT were presented. Output and transfer characteristics were used for calibration of electro-physical models implemented for HEMT simulation. Simulations in DESSIS tool showed that drift-diffusion model is not able to figure out the experimental characteristics in the full range of applied voltages. Therefore in our further work we will implement the thermodynamic or hydrodynamic models and will try to adjust physical parameters corresponding to the concentration and energy position of deep traps at individual heterostructure interfaces which can be responsible for anomalous behavior of analyzed HEMT structures.

Acknowledgement

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